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***Abstract*—Most of current works related to relay selection algorithms in cooperative communications use the Channel State Information (CSI) to decide whether to use one or another neighbor as a relay. Therefore in wireless sensor networks where the energy is the major constraint such algorithms may lead to quick battery drain of the nodes having the best links. In this paper we propose to enhance the relay selection decision process by taking into account the energy metric in addition to CSI. The results show that we can redistribute the consumed energy when we use the energy as a relay selection metric.**

***Index Terms*—Cooperative relaying, relay selection, MADM, SAW, energy efficiency,wireless sensor networks, Opnet simulator.**

I. Introduction

In wireless networks a one hop communication between a source S and a destination D, do not only concern these two nodes but also a number of their neighbors. The traffic is transmitted from S to D without any intervention of the neighbors, they passively discard the received packets. In addition if the path from S to D is noisy S will be obliged to make several re-transmissions to successfully deliver the packet.

Cooperative relaying (Figure.1) was proposed as an alternative to increase the medium capacity. It suggests employing some of the neighbors as relays to diminish the number of re-transmissions and enhance the channel's capacity. Some propose to allow simultaneous relaying by all the neighbors using Space Time Coding (STC) [1]. Others prefers to use only one relay at a time and argue that this technique can outperforms other more complicated techniques that uses multiple relays [2]. In this case, we have to select the potential relay. This selection can be performed by the source [3], [4] or by the destination [5], [6]. In almost all schemes proposed in the literature, relay selection is based on the sole parameter: Channel State information (CSI) [5], [7], [8]. CSI reflects the quality of the medium between two nodes and can be used in cooperative relaying to choose the potential relay. The issue with such strategies that considers only CSI for relay selection is that in energy constrained networks, such as Wireless Sensors Networks (WSN), they can lead to a quick battery drain of some nodes. For instance, if a node is centrally located and has that dispose of the best channels to its neighbors in a given network, it will be continuously sought to relay its neighbor's packets, in addition to its own traffic. Consequently the battery of this node will be quickly empty and the network can be divided into two disjointed parts.

A trivial solution to remedy to this problem is to use, in addition to CSI, a second relay selection metric which is the energy. The idea of this paper is to set up a simple decision tool that allow us to rank the neighbors (i.e potential relays) based on the remaining energy of a node, in addition to the CSI of both the Source-Neighbor and Neighbor-Destination channels. To do so we propose to use the Multi-Attribute Decision Making (MADM) tool to make the relay selection based on these two parameters.

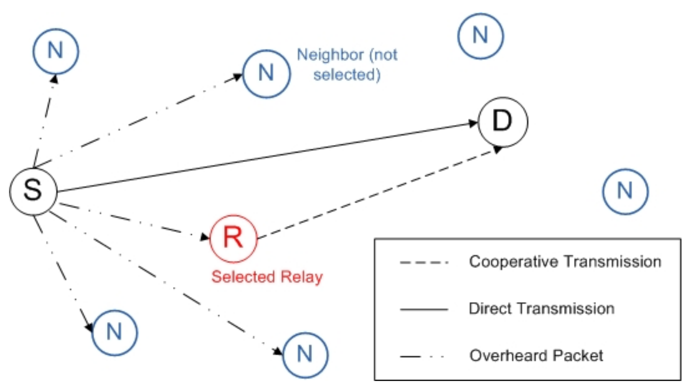

Fig. 1. Cooperative Relaying

The remainder of the paper is organized as follows: in the next section we present the details of cooperative relaying and the works that have been done so far in the literature. In section 3 we present the selection criteria and we describe the protocol that we used to evaluate the decision procedure. In section 5 we present and discuss the simulation results. Finally we conclude and present our future works.

II. Background

A. Cooperative Relaying and Relay Selection

Cooperative Relaying can be divided into three parts as shown in Figure.1: direct transmission, cooperative transmission and relay selection.

First the source transmits the packet to the destination, we call this direct transmission. In traditional cases when an outage occurs to this packet and it cannot be decoded by the destination D, S retransmits it. In addition if the medium between the source and destination is very bad S will be obliged to perform several re-transmissions and can even give up it. This causes a loss in channels' capacity and in the sources' battery. Cooperative relaying intervenes in this phase. When a packet is lost and because it is already overheard one of the neighbors will relay it to the destination avoiding the source of making several re-transmissions. We call this action cooperative transmission. The neighbor that relayed the packet is now called a Relay. Consequently cooperative relaying brings two benefits for the network: It decreases the outage probability and increase the network lifetime by redistributing the energy between the nodes [9].

Several relaying techniques were discussed in the last decades; we cite for example Amplify and Forward (AF), and Decode and Forward (DF) relaying scheme. In AF the relay amplify the received signal without verifying if there are errors. It acts as a repeater [10], [11]. In DF the relay receives the message, decodes it and verifies if it was correctly received (i.e does not contain any error). If the message is correct or it is possible to correct it, then the message is relayed. Otherwise it is discarded [10], [11].

Relay selection is the most complicated part. The best relay can be defined as the neighbor N_x (neighbor of S and D) having the best Source-N_x and N_x-Destination channels (lets denote the CSI of these channels by respectively CSI_{S-N_x} and CSI_{N_x-D}). To select the best relay, we have to assess these channels at each transmission or determine the harmony period of the channel after which the previously assessed CSIs are no more valid. Once this performed, a global CSI (CSI_G) that represents simultaneously the quality of the both channels, have to be calculated. Different strategies exist to calculate $CSI_G = f(CSI_{S-N_x}, CSI_{N_x-D})$. For this paper we adopt the strategy described by function 1.

$$CSI_{G_{S-N_x-D}} = Max_{\{N_x \in N\}}\left(Min(CSI_{S-N_x}, CSI_{N_x-D})\right) \quad (1)$$

where $CSI_{G_{S-N_x-D}}$ is the global CSI of the channel $S-N_x$ and $N_x - D$, and N is the set of neighbors. With this function the selected relay is the one having the best worst of both channels $S-N_x$ and N_x-D. This means that a given neighbor must have two good channels ($S-N_x$ and N_x-D) to be able to relay the packet. Otherwise if one of these channels is bad the packet will be prone to corruption and the relaying loses its benefits. This strategy proved to outperform other techniques like harmonic mean [12].

B. Simple Additive Weighting

Multi-Attribute Decision Making (MADM) is a process for making decision over several alternatives characterized by multiple parameters. It allows evaluating the available alternatives even in the presence of conflictual parameters. In addition some MADM techniques are simple and do not require high computing power. One of these techniques is Simple Additive Weighting (SAW). SAW calculates a score to evaluate each alternative. Suppose that we have an alternative represented by the vector V = $(V_1, , V_i, ..., , V_n)$. The score of V is calculated using Formula 2.

$$Score(V) = \sum_{i=1..n} C_i \times V_i \quad (2)$$

Where C_i is the coefficient of the parameter V_i and n is the number of parameters. In the case where we have incoherence in units, we have to normalize the vector of each alternative. We divide each component V_i of the vector of the alternative V by a given constant in to get the entire component within the interval [0..1]. Despite its simplicity, SAW proved to have better performances than other MADM techniques [13].

C. Description of the protocol

To test our decision process we use an existing Cooperative MAC protocol [5]. Figure 2 describes the sequence of packet exchange to send one data packet. We suppose that the routing path is already established and that each node already knows the next hop to the destination for each packet. The cooperative relaying will concern each hop within the routing path. The source S has a packet to send to the Destination D. S begins by sending a Ready-To-Send (RTS) message to D. D replies with a Clear-To-Send message. The RTS/CTS exchange serves at the same time to reserve the channel and to evaluate the channels quality between respectively the source and neighbors and neighbors and destination. The neighbors who hear both RTS and CTS messages deduce that they are potential relay. They calculate the CSI of the S-R channel from the signal of the received CTS and the CSI of the R-D channel

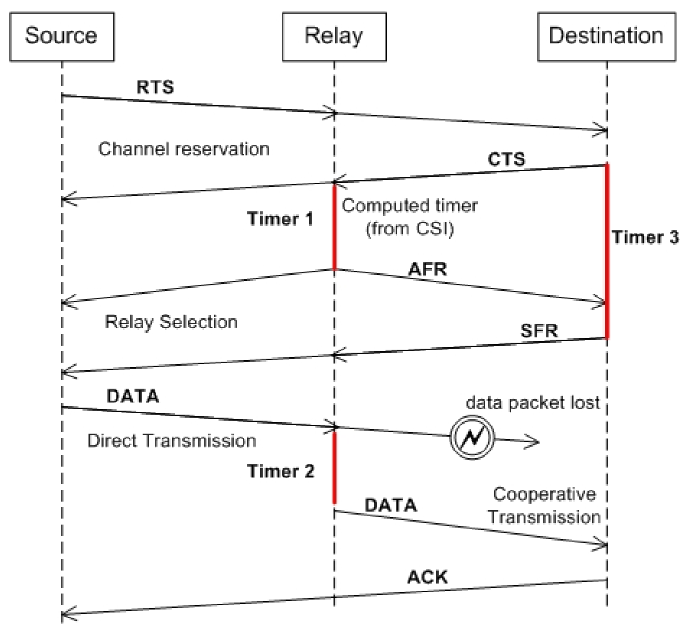

Fig. 2. In the case where the destination need a packet relay

from the signal of the received CTS message. From these two CSI values they calculate a global CSI (CSI_G) reflecting the quality of both channels from which they deduce the timer. They set this timer and start a contention period. The timer of the neighbor having the both "'best channel"' S-R and R-D will expire first (Timer 1 in Figure 2). The neighbor sends then an Apply-For-Relay (AFR) message to declare that he will be the relay. Receiving the AFR, the destination will reply with a Select-For-Relay (SFR) message informing the neighbors that did not eventually heard the AFR that a relay had been selected. Now the source can send the data packet. The relay stores the packet. If the destination were able to decode the message then it sends an Acknowledgment (ACK) to S. If not, it sets a timer (Timer 3 in Figure 2) and waits for the Relay. If the relay was able to decode the data packet and D does not sent the ACK after a certain time (Timer 2 n Figure 2), it will sends the packet to D. In the case Timer_3 (Figure 2)will expires without receiving the relayed copy, D will deduce that the Relay was not able to decode the data packet neither. The source proceeds to a re-transmission.

Let's note that some neighbors retire from the relay selection process before hearing the AFR messages. Each node maintains CSI thresholds if the CSI of one of the channels is below it the node decide that he cannot enhance the direct communication and retires.

III. Enhanced Relay Selection Decision

As depicted earlier, the energy is the most important constraint in a Wireless Sensor Network. Each node has to manage intelligently its energy. Cooperative relaying comes to enhance this energy management. Therefore a bad configuration of the network can lead to opposite results. For instance in a network where we have a steady configuration of the best relays (i.e. the same neighbors are always elected as relays), these relays will continuously relay the packet of their neighbors. In this case cooperative relaying preserve the property of decreasing the outage rate but looses the property of energy distribution.

Consequently relying completely on the CSI is not the best choice in an energy constrained network. Therefore we propose to enhance the relay selection process. We continue to use timers of the protocol in section II-C to elect the best neighbor as a relay but we modify the way of computing it and the parameters used for. First of all we include the remaining energy as a second parameter in the relay selection process (the first parameter is CSI). Then we use the MADM technique *Simple Additive Weighting* (SAW) to select the best neighbor as relay.

The CSI is calculated using the RTS/CTS as described in section II-A using the following formula

$$Score = \alpha \times CSI_G + \beta \times RE \quad (3)$$

where α and β are respectively the weights of the Global Channel State Information CSI_G and of the Remaining Energy (RE). Therefore from two nodes having nearly the same CSIs, we choose the one having more energy. The neighbors of a pair Source-Destination use the heard RTS-CTS to evaluate the channels from source and to destination. They use the formula 3 to calculate their scores. The neighbor computes the global CSI and determines the remaining energy then normalizes these values. Finally the score is the weighted sum of the normalized CSI and remaining energy.

The neighbor having the higher score is the one to be elected as relay. Each neighbor set a timer T deduced from the computed score ($T = \frac{1}{Score}$), after which it will eventually declare itself as relay by sending the AFR. The neighbor that hears AFR deduces that another neighbor computed a better score and will be elected. This timer computation is executed once for each potential relaying operation. Its complexity is constant since the number of arithmetic operation is always the same. Therefore it will not be difficult to implement it on a sensor node.

IV. Simulations

A. Environment

In order to evaluate our decision algorithm we implemented it with the protocol described in section .II-C on Opnet 15.0 simulator on a windows environment. All simulations are made on wireless sensor networks. The simulated sensors are equipped with a unique antenna and are not able to send and receive at the same time. They all use the same channel on the 2.4 GHz band. The CSI of the channels may vary but the order of the global CSI of the neighbors remains the same.

Without loss of generality we suppose that our nodes are in these states: transmitting, receiving, Idle and sleeping. Each sensor is equipped with an AA battery. The energy consumption in each state is of a Micaz sensor node [14] and resumed in Table .II. The source S sends periodic traffic to D, a data packet each 6 hours. The size of the packets used is described in Table .I and the data rate is fixed to 250 Kb/s. The structure of the network is formed once at the beginning of the simulation and we do not consider mobile nodes. In addition we suppose that all the channels are symmetric.

All the nodes become awake at the same time and during the transmission of the message of S and return to sleep after hearing the ACK from the destination. In our simulation all the neighbors are able to relay the packets from the source to destination, we suppose that the neighbors unable to relay packet (those having their CSI under the pre-defined threshold as described in section.II-C) have already retired.

Packet Type	Packet Size (bits)
RTS	24
CTS	24
AFR	24
SFR	24
ACK	24
DATA	1016

TABLE I
SIZE OF PACKETS

Action Type	Consumption
Transmission	17.4 mA
Reception	19.7 mA
Idle	20 μA
Sleep	1 μA

TABLE II
ENERGY CONSUMPTION (MICAZ [14])

B. Scenarios

Our network is composed of a Source S, a Destination D and Three potential relays R_1, R_2 and R_3 (Figure .3). We suppose that the relays dispose of global CSI slightly different in the following order $CSI_{G_{S-R2-D}} \succ CSI_{G_{S-R1-D}} \succ CSI_{G_{S-R3-D}}$. At the beginning of the simulation all the nodes have the same amount of energy and no other traffic is disturbing the packets from S to D. The probability to relay packet is set to 40%. We focus on the energy consumption of the relays and on network life time defined as the time until the first node in the network dies.

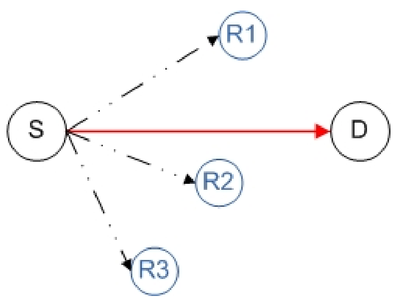

Fig. 3. simulated scenario

In the first scenario we execute the relaying protocol (described in section II-C) with a decision based only on the CSI. The source is the first node to die. The results of the simulation show that in this case only one neighbor is always elected as relay which is R2 as shows Figure .4. Each time it will sends the AFR to announce that it is the best relay and when D does not sends the ACK messages R2 will relay the data packet. Since it is the most solicited, its energy consumption rate is highest than that of the neighbors R1 and R3 (Figure .5)its battery is at 25% while the levels of the batteries of R1 and R3, which are less solicited, are at 58%.

In the second scenario we introduce our decision algorithm with α and β equal to 0.5. In this case the 3 neighbors participate all in relaying the source's packets. The three relays alternates on relaying the packets of S. Figure.7 describes the selected relay during a short period of the simulation. Depending on the energy level of the neighbors the selected neighbor to relay the packet will be different. The rhythm of energy consumption is smoother as shows Figure .6. Therefore the levels of the relay's batteries are decreasing in parallel and the energy consumption is distributed between the relays. . The battery level of the node was around 44%. The lifetime of the network remain the same because the algorithm do not

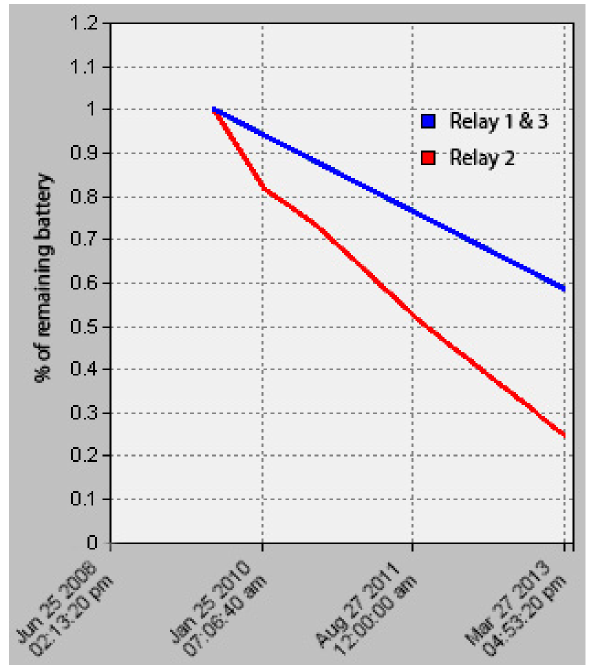

Fig. 4. Energy Consumption with a decision based only on CSI

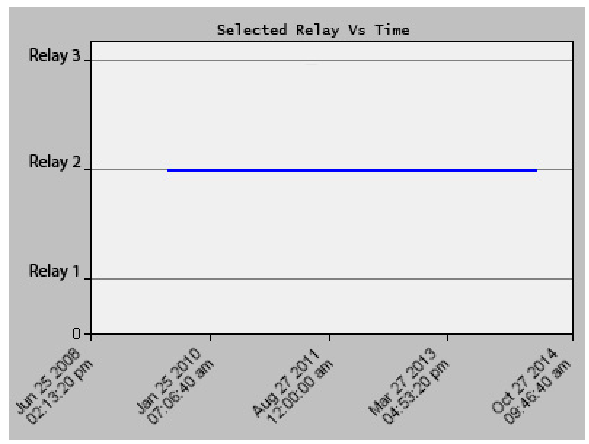

Fig. 5. The selected relay with a decision based only on CSI

intervene on the behavior of the source node.

In order to energy consumption of the relays in the previously described simulation conditions, it is better to integrate remaining energy as a second parameter in the relay selection decision. Despite the simplicity of the decision algorithm we show that we are able to preserve more energy.

V. CONCLUSION

During the last decades, cooperative relaying have proved to be a good solution to enhance the medium capacity and several research have been done in this domain. The selection of the best relay remain an open research area. In this context we proposed in this paper an enhanced relay selection algorithm that take in consideration the energy in addition to the CSI and we used MADM as a mathematical tool. It was demonstrated that by using a simple mathematical tool we can redistribute

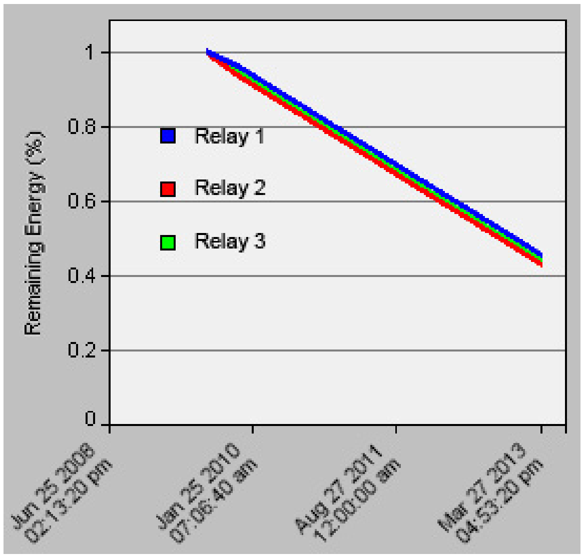

Fig. 6. Energy Consumption with a decision based on CSI and on remaining energy

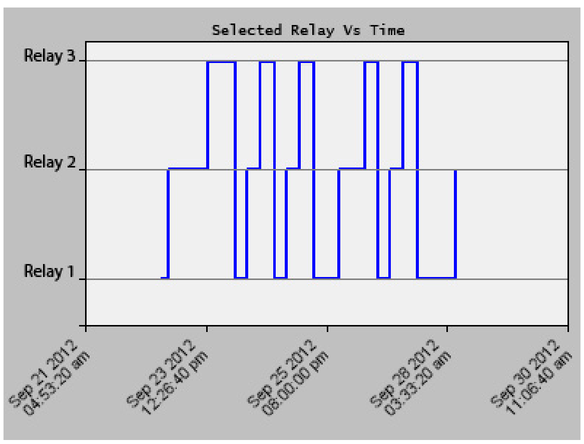

Fig. 7. The selected relay with a decision based on CSI and on remaining energy

the energy consumed by the relays. Furthermore we still able to reduce the amount of consumed energy; the protocol present a lot of overhead and some nodes are listening to the medium without participating in the relaying process. In the future work we aim to reduce the number of control packet, to make nodes less active and to study the impact of the values of α and β on the network life time.

References

[1] Z. Li and X.-G. Xia, "A simple alamouti space-time transmission scheme for asynchronous cooperative systems," *Signal Processing Letters, IEEE*, vol. 14, no. 11, pp. 804–807, 2007. [Online]. Available: http://dx.doi.org/10.1109/LSP.2007.900224

[2] A. Bletsas, H. Shin, and M. Win, "Outage-optimal cooperative communications with regenerative relays," in *Information Sciences and Systems, 2006 40th Annual Conference on*, March 2006, pp. 632–637.

[3] E. Beres and R. Adve, "On selection cooperation in distributed networks," in *Information Sciences and Systems, 2006 40th Annual Conference on*, March 2006, pp. 1056–1061.

[4] P. Liu, Z. Tao, and S. Panwar, "A cooperative mac protocol for wireless local area networks," in *Communications, 2005. ICC 2005. 2005 IEEE International Conference on*, vol. 5, 2005, pp. 2962–2968 Vol. 5. [Online]. Available: http://dx.doi.org/10.1109/ICC.2005.1494934

[5] H. Adam, C. Bettstetter, and S. M. Senouci, "Adaptive relay selection in cooperative wireless networks," in *Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on*, 2008, pp. 1–5. [Online]. Available: http://dx.doi.org/10.1109/PIMRC.2008.4699593

[6] R. Madan, N. Mehta, A. Molisch, and J. Zhang, "Energy-efficient cooperative relaying over fading channels with simple relay selection," *Wireless Communications, IEEE Transactions on*, vol. 7, no. 8, pp. 3013–3025, August 2008.

[7] A. S. Ibrahim, A. K. Sadek, W. Su, and K. J. R. Liu, "Cooperative communications with relay-selection: when to cooperate and whom to cooperate with?" *Wireless Communications, IEEE Transactions on*, vol. 7, no. 7, pp. 2814–2827, July 2008. [Online]. Available: http://dx.doi.org/10.1109/TWC.2008.070176

[8] H. Adam, C. Bettstetter, and S. Senouci, "Multi-hop-aware cooperative relaying," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, April 2009, pp. 1–5.

[9] N. Shastry, J. Bhatia, and R. Adve, "Theoretical analysis of cooperative diversity in wireless sensor networks," in *Global Telecommunications Conference, 2005. GLOBECOM '05. IEEE*, vol. 6, Dec. 2005, pp. 3269–3273.

[10] A. Nosratinia, T. Hunter, and A. Hedayat, "Cooperative communication in wireless networks," *Communications Magazine, IEEE*, vol. 42, no. 10, pp. 74–80, Oct. 2004.

[11] J. Laneman, D. Tse, and G. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *Information Theory, IEEE Transactions on*, vol. 50, no. 12, pp. 3062–3080, Dec. 2004.

[12] A. Bletsas, A. Khisti, D. Reed, and A. Lippman, "A simple cooperative diversity method based on network path selection," *Selected Areas in Communications, IEEE Journal on*, vol. 24, no. 3, pp. 659–672, March 2006.

[13] S. H. Zanakis, A. Solomon, N. Wishart, and S. Dublish, "Multi-attribute decision making: A simulation comparison of select methods," *European Journal of Operational Research*, vol. 107, no. 3, pp. 507 – 529, 1998. [Online]. Available: http://www.sciencedirect.com/science/article/B6VCT-3TC6THR-1/2/361b4a418d05d38a4adde4694f8c0add

[14] www.xbow.com, "Micaz 2.4ghz," 2009 (accessed August 14, 2009). [Online]. Available: http://www.xbow.com/Products/Product_pdf_files/Wireless_pdf/MICAz_Datasheet.pdf